Residential Water System Circuit Breaker for Monitoring of Abnormal Use

A Senior Project Presented to the Faculty of California Polytechnic State University, San Luis Obispo

In Fulfilment of the Requirements of the Degree Bachelors of Science in Materials Engineering

By

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June 1, 2012

Approval Page

Project Title: Residential Water System Circuit Breaker for Monitoring of Abnormal Use

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Date Submitted: June 1, 2012

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Abstract

Most residential housing units do not have preventative measures in place to stop water flow into the house in the event of a water crisis. A residential water system circuit breaker was designed and fabricated to monitor water flow with logic able to recognize abnormal excess water flow. Upon recognizing irregularly large volumetric flow, the device will shut water supply off to the residence to prevent wasted water and water damage to the property. The design was based on ½" diameter pipe fittings and would be solar powered in order to remove the dependence of the electrical grid. An electronic hall-effect flow sensor will communicate with a microcontroller to quantify inlet volumetric flow. The device's performance was tested using a recirculation pump with flow rates between 0-17 gallons per minute to simulate random residential water usage. During a sample monitoring period of each trial, an average maximum flow rate was calculated; water was then pumped at a constant 17 gallons per minute and the time to actuate the solenoid valve was the measured variable. These values were compared against theoretical values based on the logic programmed to the systems microcontroller. Results showed all experimental values to be within 4 second standard deviation with an average offset of 7 seconds. With the current software the device portrays positive performance results of recognizing an abnormal flow rate and actuating preventative flow stopping measures.

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Key Terms:

Block flow rate – The average flow rate calculated by the microcontroller every 5 seconds

Dynamic Pressure - The pressure while water is flowing in fluid dynamics

Fluid Dynamics – A subsystem of physics and fluid mechanics that deals with fluid flow

Hall Effect – The production of a voltage difference across an electrical conductor, transverse to an electric current in the condor and a magnetic field perpendicular to the current.

HDPE – High-density polyethylene is a polyethylene thermoplastic made from petroleum.

Laminar Flow – A classification of flow in which particles in a fluid move in streamlines and motion of particles in a flow is predictable

Materials Engineering – An interdisciplinary field involving the properties of matter and its applications to various areas of science and engineering

Printed Circuit Board (PCB) – Used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces

PVC – Polyvinyl chloride is a thermoplastic resin.

Stagnation Pressure – In fluid dynamics, stagnation pressure is the static pressure at a stagnation point in a fluid flow. In the case of this report this stagnation point is the valve.

Static Pressure – The pressure of a fluid on a body when the body is at rest relative to the fluid.

Transitional Flow – An intermediate type of fluid flow which has characteristics of both laminar and turbulent flow

Turbulent Flow – A flow in which the velocity at any point varies erratically and the path of a particle in the fluid can no longer be predicted.

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1. Introduction

The following report is a study on the prototyping and testing of the design of a residential water system circuit breaker for monitoring of abnormal use.

1.1 Problem Description

In the United States and other first world countries, people have the privilege of having public utilities readily available to them. Most citizens do not realize that with this privilege comes an accountability to consume these public resources responsibly. This includes being aware of personal usage as well as having preventative measures in place in case of an emergency.

Electrical circuit breakers are required in every residence to prevent an overload on the circuitry for the safety of persons and appliances. In almost all residences, apartments, and industrial buildings, there are no procedures in place to prevent fruitless water use. Many people use water carelessly without thinking twice about taking a long shower or leaving the sink on too long. In reality, water is a depleting resource and education to preserve it must be implemented. The first step to educate persons to cut back on their water consumption would be to show them a visual of their day to day usage.

The average daily household consumption per capita is 69 gallons of water excluding outdoor water use[3] (Figure 1). On average the entire household will consume a whopping 350 gallons per day including outdoor usage. In most countries, consumers do not pay the actual cost of water because governments subsidize the water supply. Although these subsidies carry their obvious benefits, the result is that the people do not appreciate what they are receiving. On average, approximately 40% of municipal water suppliers worldwide do not charge enough for water to meet their basic operating costs. In some cases water is available for almost nothing. This leads to excessive waste; the average daily American household consumption is equivalent to the water used by an entire village in Africa in the same period of time. Water is currently managed as if it were worthless when, in fact, it is an increasingly scarce life-sustaining resource.[2]

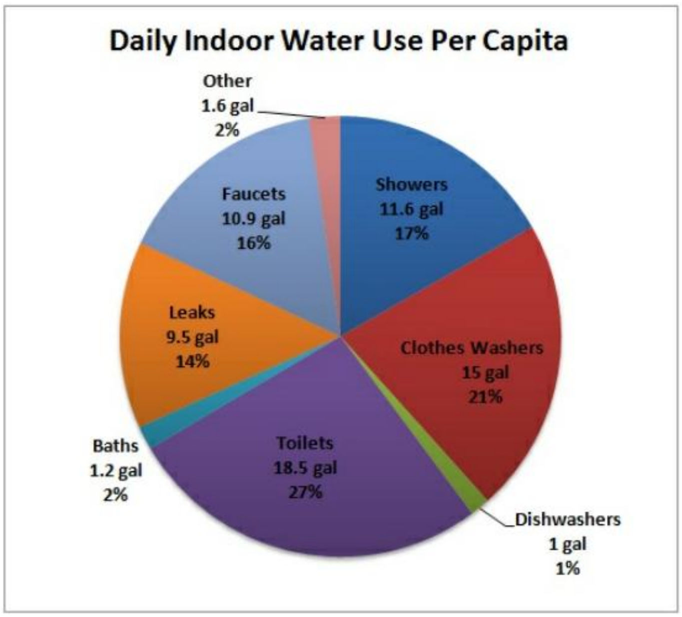

Figure 1: The pie chart depicts the average residential indoor water per day and where it is used by Americans.[3]

Not only is water a vital natural resource to conserve, but when plumbing problems arise, this resource can impart irreversible damage. When failure occurs in the piping of the water system, there is usually nothing besides human interaction that can prevent water damage and unwanted excess flow to take place for minutes, hours or even days. In some cases, no one will be home to notice the failure, or it will go unnoticed for various other reasons.

1.2 Broader Impacts / Realistic Constraints

In addition to traditional technological and economic considerations fundamental to the design of any system, the broader impacts of design should be considered to understand how the design will affect society as a whole. Consideration of realistic constraints is particularly related to the better-off today's society and quality of life. The four constraints that will be examined are sustainability, economical, environmental, and social.

1.2.1 Sustainability

Sustainability is often judged by a product's ability to satisfy the triple bottom line. A sustainable product must therefore be economically viable, socially equitable, and environmentally sound. These three considerations were accounted for when developing design requirements for the device.

Sustainability also encompasses reliability. The product must be designed to endure many years of service without failure. For this design, a target of 10 or more maintenance-free years of service was chosen. The device was therefore designed with minimal moving parts in order to increase reliability.

1.2.2 Economical

The device was designed to be made at a cost competitive price in order to be a viable solution to preventing water damage in a household in an emergency. A customer must agree to an economic benefit in order to purchase a product. The apparent benefit for the water circuit breaker being that in the event of an emergency, the system will save the customer money that would otherwise be spent on damages and excess water bills. The system is becoming more economically viable due to the fact that all over the world the price of water has been increasing. For example, in the five years between 2005 and 2010, municipal water rates increased by an average of 27% in the United States, 32% in the UK, 45% in Australia, 50% in South Africa, and 58% in Canada.[2] With these rising prices, people will need systems in place to prevent useless loss of this valuable resource.

After installation of the system, the user will be able to view their day to day water consumption. It is possible that household water usage would decline because the user is able to improve upon their consumption through conservation. This would also directly decrease the cost of their water bill.

Ideally there would be no maintenance costs, and installation could be done by the customer, or by a trained city official for a small cost. A comparison of the cost of existing products on the market and their features will be mentioned later in the report.

Upon marketing and production of such a product, there would likely be house insurance deductions for installing the device in a home. This would be yet another additional savings to the user for purchase and installation of the system.

1.2.3 Environmental

In 2005, approximately 3.8 billion gallons of water per day were consumed for domestic use and this number has only increased in years since. [1] With growing populations and economies, the scarcity of good-quality water is on a rise. Today, one in three people worldwide live in water-scarce regions.[2] It is becoming increasingly apparent that water scarcity, not future oil shortages or global warming, is the single greatest crisis facing humanity in the 21st century and possibly beyond. It is estimated that the amount of water available per person will shrink by one third in the next twenty years.[4] Water conservation must be started and practiced while it is still readily available to the public.

With use of this system, water related residential damages may be reduced or eliminated by selectively preventing flow of water into a residence. Without such a system, the possibilities are endless as to the extent of damage water can do, and resulting damages would vary depending on location and severity of overflow. It is possible that the damages could extend beyond the property of occurrence and into neighboring or public properties. Valuable electronic components will be especially vulnerable to such an event. Damaged devices and materials will likely be in a state beyond repair and likely sent to a nearby landfill.

The materials designed to be used in the water circuit breaker must be carefully selected because they will be in direct contact with drinking water. Contamination or pollution of the water supply was considered and carefully avoided.

1.2.4 Social

Despite the other pressing realistic constraints, the social impact is the most imperative and has unimaginably high potential. With implementation of this system in residences across the country or world, the hope is that knowledge of water conservation will increase water frugality amongst those who use the system. By purchasing such a device to be used in a residence, the device will impart knowledge of how vital water conservation is. After installation of this device in a residence, knowledge of water conservation will literally hit home. The spread of this knowledge will be equally as important as the use of the system itself.

It is hoped that the system will be subsidized in order to make the system affordable for even households of the lowest incomes. The system was designed to be as affordable as possible with the intention that anyone would able to purchase and install it in their home. A larger and more robust version can also be made available for apartment, industrial buildings, or irrigation systems.

With these systems installed in many homes, it is possible that when these users leave their home to go to their place of work, they take with them their knowledge of conservation and apply it to their industry. The result would lead to a decrease in industrial water use as well. This occurrence has to potential to be a tremendous impact since industrial water use accounts for 4% of the total water consumed (Table I), not counting those industries connected to the public supply. This percentage may seem small, but only because the total volume of water consumed per day in the United States is enormous.

Table I: Source of daily water use in 2005 in the United States[1]

Source of Consumption	**Total Water Use (billion gallons per day)**	**Percent of Total Daily Use**
Domestic	3.83	1%
Public Supply	44.20	11%
Industrial	18.20	4%
Irrigation	128.00	31%
Thermoelectric	201.00	49%
Mining	4.02	1%
Livestock	2.14	1%
Aquaculture	8.78	2%

1.3 Fluid Dynamics Background

Research was conducted on the fluid dynamics of pipe flow inside of a residential plumbing system in order to understand all aspects of the design. It was found that the pressure inside residential pipes is typically on the order of 80 psi. At times pressure spikes can occur at any moment in the water supplied from the city that can reach upwards of 150 psi.[5] These pressure spikes cause fracturing of piping or other components resulting in a leak or flood. It should be noted that although the standard cross sectional inlet of most residential homes is 5/8 inch diameter, ½ inch diameter will be used for this project due to availability.

Since the conservation of mass theory states that the rate at which mass flows through a pipe will not change, this means that velocity and pressure will change with a change in cross sectional area of the pipe.[7] This is confirmed by Bernoulli's equation which will be mentioned later in the report. In this case, gravity plays a negligible role; therefore pressure differences drive fluid flow through the pipe. When examining the velocity profile of a liquid through a pipe, the speed of the liquid varies depending on its position in the pipe cross section. Liquid near the surface of the pipe's inner wall is slowed by frictional interactions with the solid surface of the wall (Figure 2). It is important to determine the nature of the water flow in application because increasing turbulence in the pipe will increase losses due to friction.[7]

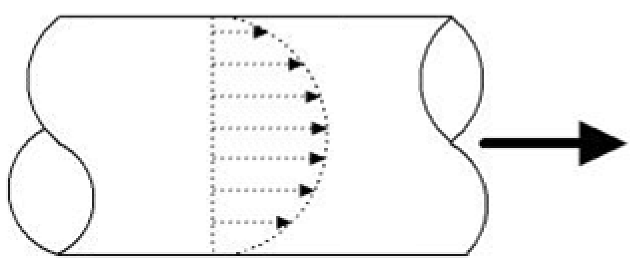

Figure 2: The schematic shows how velocity of a fluid changes with cross sectional location in the pipe

1.3.1 Turbulent Flow Confirmation

The exact nature of the water inside of the pipe was further investigated to distinguish whether the nature of the water was turbulent flow, laminar flow, or transitional. Turbulent flow is likely to occur in situations with a large pipe diameter and high flow rate and thus was hypothesized to be the conditions in this application. This theory was confirmed using Reynold's equation (Equation 1). A Reynold's number above 4000 is considered to be turbulent flow. [7] The minimum velocity for turbulent flow was calculated and compared against a measured velocity. The velocity from one open faucet was measured because it simulates low velocity and flow will become more turbulent at higher speeds. An average speed of 7.5 ft/sec was determined by measuring the time to fill a gallon of water. Below is the calculated minimum velocity for turbulent flow to occur.

$$Re = \frac{\rho v D}{\mu} \tag{1}$$

Re:	Reynold's number	= 4000
ρ:	density	= 1.936 slugs / ft^3 @ 70°F
D:	pipe diameter	= 0.5 in
μ:	viscosity	= 2.037×10^{-5} lb s / ft^2 @ 70°F
v:	velocity	= 1.01 ft/s

This calculated velocity of 1 ft/s is far below the measured value of 7.5 ft/s second and it was therefore confirmed that the flow is turbulent in this application. A sensitivity analysis was performed by changing the pipe diameter and results did not change.

1.4 Existing Products

Currently there are some products on the market with the ability to do such things as actuate the closing of a valve upon sensing a leak. Capabilities of these various products can be seen in Table II. All of the existing products require connections to the electrical grid, which can pose problems in the event of a power outage. No existing product was found that has a volumetric flow sensor. Most systems involve leak sensors that must be strategically placed around a household to sense water in typically dry areas. Other systems involve remote user actuation, so that a user can shut off the water supply when away from their home. No system was found that involved a volumetric flow sensor with integrated logic to automatically actuate a valve. Also, none of these systems give the user feedback as to how much water is being consumed.

Table II: Comparison of design with existing products

	Water Circuit Breaker	**Pipe Burst Pro Jr.**	**HousEvolve**	**Wireless FloodStop**	**WaterCop**
Price	~$650	$557+	$519	$371	$371
Energy	Solar powered battery	120VAC	120VAC with backup battery	120VAC	120VAC
Sensor	In pipe	External Sensors	External Sensors	External Sensor	External Sensor
Feedback Monitoring	Yes	Leak/No Leak	Leak/No Leak	Leak/No Leak	Leak/No Leak

1.5 Problem Statement

Household, business, and public water pipes can lead to leakage and overflow upon failure. The resulting damage can be catastrophic particularly in places without full time tenants and multi story buildings. A system is needed for these rare occurrences to stop water flow and prevent further damage and wasted water.

1.6 Objective

The objective of this project is to develop a system to be used in the case of emergencies that will be able to recognize when an emergency takes place in a plumbing system and be able to stop water flow. A parallel objective is to implement awareness of water conservation in the minds of those who chose to install the product in their homes.

1.7 Design Requirements

1. Be able to close a valve after a threshold of total volumetric flow is exceeded
2. Be completely stand alone and function without external energy or user input
3. Monitor flow and give the user real-time feedback
4. No failures for 10 years
5. No disruption of quality of water supply

2. Design Development

The following section will report on the conceptual design of the water circuit breaker system and the various concepts that were considered.

2.1. Valve

The decision of what kind of valve to be used in the design of the system was between either mechanical or electrical actuation. Most solenoid valves that operate at higher pressures require more electrical current to actuate. With a system that is completely off the 110 VAC electrical grid, this requires a battery with enough energy at a given moment to actuate the valve and remain actuated. In this application, a normally open valve would be used; meaning that current is only drawn from the battery when the valve is closed. If this valve is closed for an extended period of time due to lack of human interaction, this would of course drain the battery resulting in the valve to reopen and allow further damage and water waste.

The advantage of a mechanical valve being that it would require little to no electrical power in order to close. In the case of a spring loaded gate valve, a small electrical actuation would be needed in order to release the energy stored in the spring. The advantage here is that no current would be drawn while the valve is closed. The issue with this design is that work must be done in order to reset the valve and restore energy. The result is two possible designs; one in which the user will have to rewind the valve to restore energy in the spring; the other being that a motor would be used to load the spring.

A decision matrix of the nature of the valve can be seen in Table III. Each performance requirement has been assigned a performance factor based on design requirements. Then each design is assigned a value between 0 and 10 based on how well it performs in each department. The totals of each value multiplied by the corresponding performance factor can be seen in the bottom row. The design with the highest value is the solenoid valve. A sensitivity analysis was performed on these results by slightly varying each value; it was concluded that the results are not sensitive and the solenoid valve outperformed the other two designs.

Table III: Valve Design Decision Matrix

	Performance Factor	**Solenoid Valve**	**Mechanical Actuation w/ User Reset**	**Mechanical Actuation w/ Electrical Reset**
Cost	0.18	3	9	5
Manufacturability	0.20	10	5	2
Power Consumption	0.22	6	10	6
Ergonomics	0.20	10	1	10
Disruption of Water Supply	0.20	8	10	10
Total	1	**7.46**	7.02	6.62

2.2. Flow Sensor

Based on the comparison existing product designs, it was concluded that a flow sensor would need to be located inside of the pipe walls, rather than an external leak sensor similar to existing products. An interior sensor design will be able to give the user an accurate value of volumetric water consumption. In the case of the flow sensor making direct contact with the residence's water, the design chosen must not disrupt the water quality in any way.

2.2.1. Impeller Generator

Conceptual designs were developed in order to obtain flow rate values while harnessing energy from the flowing water and use this energy to charge the battery. The conceptual design consisted of a rotating impeller inside of the pipe walls. The impeller blades would have alternating magnetic poles on the outer edges close to the pipe wall. As water flowed through the pipe, the impeller would rotate. Through magnetic induction, this rotation would in induce a current in copper coils wound around the exterior of the pipe. This current could be used to trickle charge the battery to ensure that the battery would have enough energy to actuate closing of the valve. The performance of the power generated would be largely variant and dependent on the quality of the manufactured system. Power produced would be a factor of coil windings as well as distance of the magnets to the copper coils.

Flow measurements of this design could be taken from the resulting voltages during rotation. Voltage spikes could be converted into revolutions and then into flow rate. Despite the appealing nature of producing power from the water flow, manufacturability of such an impeller would be low.

2.2.2. SeeedStudio Flow Sensor

Another option to sensing volumetric water flow would be to purchase an existing product (Figure 3). This would greatly increase manufacturability of the system as well as decrease initial cost. Similar to the impeller generator, this device is a Hall Effect sensor that varies its output voltage in response to a magnetic field. This sensor is safe to use with drinking water and its body is made of a composite PA66+33% glass fiber and can withstand over 250 psi. This particular sensor is capable of monitoring up to 16 gal/min.

The disadvantage of this design would be that it would not generate power, and would instead require a maximum of .075 W input. Therefore, the system would require some external form of power generation.

Figure 3: The picture portrays the water flow sensor manufactured by SeeedStudio.

2.2.1. Pitot Tube Sensor

A pitot tube (Figure 4) is a design that was also considered as an option to sense water flow. The design takes pressure measurements in the pipe which can then be converted into volumetric flow measurements using Bernoulli's equation (Equation 2):

$$P_t = P_s + \frac{\rho V^2}{2} \tag{2}$$

V = Fluid velocity

P_t = Stagnation or total pressure

P_s = Static pressure

P = Fluid density

The pitot tube sensor design would require a form of electrically communicating flow velocity to the microcontroller. This would entail a power input as well as additional cost. This sensor's design was considered to have mediocre manufacturability.

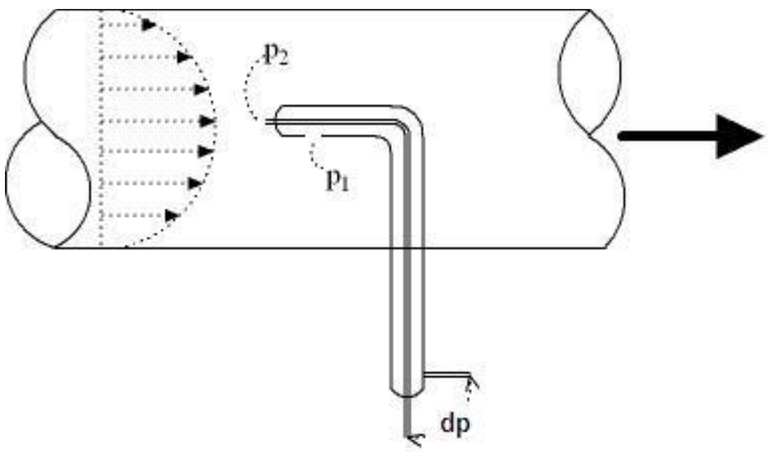

Figure 4: The schematic above portrays how a pitot tube uses pressure change in order to give a value of water flow

2.3. Software

By far the most difficult task for this system is to distinguish the difference between a leak and a spike in water usage. The software developer must also carefully find a medium between not recognizing a leak and actuating too many false alarms. The logic on the microcontroller can therefore be designed in a variety ways. This aspect of design is imperative because the software must make sure that the valve closes when it needs to, but does not intervene in the event of a false alarm. The automated system must perform with minimal user interaction. The valve should not always close during high volumetric flow rates, but rather when these high flow rates persist for an abnormal period of time.

First, there must be a sample period after installation which would monitor typical water usage. Since water usage is different for every household, this stage is critical for quantifying typical usage. It is crucial during this sample period to gather as much information as possible about typical usage, and apply the information learned to the normal operation monitoring. Based on the flow trends of this sample period, the software should be able to predict whether a crisis is present in the plumbing system. In application, this sample period would be on the order of seven days.

Integrating the incoming volumetric flow rate with respect to time would result in a volume of incoming water per unit time. This integration would be ideal for determining if there is a problem and whether intervention is needed. Preferably the period of integration could be different for households and would be calculated based on the usage during the sampling period. At a time of crisis, if an integrated flow rate exceeds the average by a multiplying factor, then the valve would be triggered to close.

3. Final Design Description

Due to the cost constraints of the project, solenoid valve manufacturers were sought out for sponsorship. The companies Bürkert GmbH and Spartan Scientific responded and were each willing to sponsor and supply 12 VDC valves with specifications capable of withstand pressures of approximately 150 psi. A comparison of the two valves (Figure 5) can be seen in Table IV. The performance of both valves was tested and final design decision was made based on the results.

Table IV: Comparison of Valve Specifications

	Bürkert 5282	**Spartan 3510**
Body Material	Brass, stainless steel	Du Pont Zytel 77G33 glass filled nylon
Pressure Range	2.8-145 psi	0-150 psi
Voltage	12 VDC	12 VDC
Power Consumption	8 W	10 W

A)

B)

Figure 5: The image A) above is a view of the Bürkert 5282 solenoid valve. B) is the Spartan 3510 series solenoid valve

A 12 V lead acid battery with 1.2 A hr was chosen to supply power to the system. The SeeedStudio flow sensor design was selected to monitor water flow because of cost constraints and its ease of manufacturability. In order to ensure that the battery will have enough power, a 20 cell solar panel (Figure 6) will charge the battery. The microcontroller used was an Arduino Fio. A Bluetooth module will be used with the microcontroller in order for the user to easily communicate with the system. A system block diagram of the final design of the system can be seen in Figure 7.

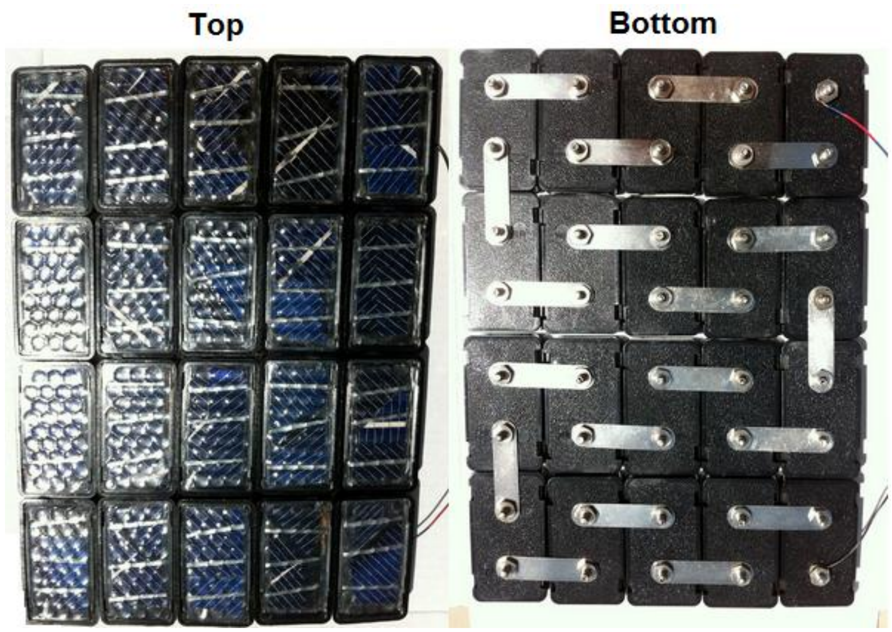

Figure 6: The image above shows the top and bottom of the 20 solar cells arranged in series.

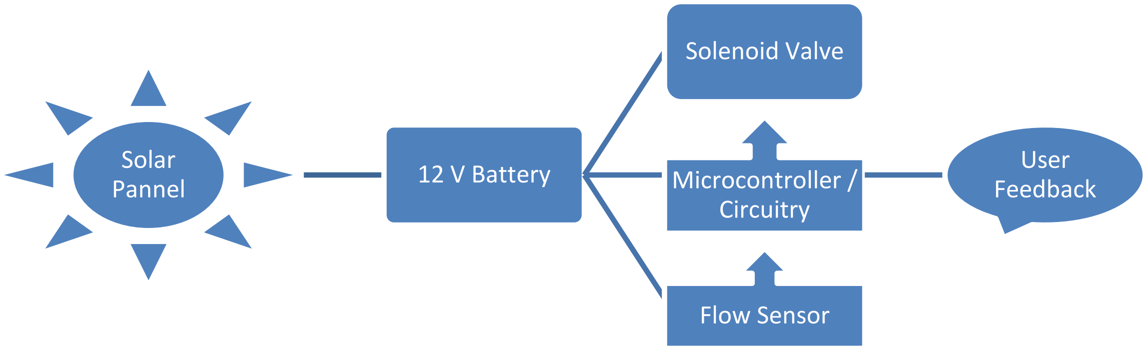

Figure 7: The image above is a system block diagram of the inputs and outputs of the system as well as the transfer of logic and energy from one subsystem to another.

3.1 Electrical Circuitry

Currently, copper wiring coupled with a bread board is used to connect the various electrical components. For further design work would include the fabrication of a printed circuit board (PCB) in order to simplify and compact the system as well as ensure reliable electrical connections.

The output voltage of the microcontroller is 3 V, therefore a 5 V relay was needed to supply power to the solenoid valve upon actuation of from the microcontroller. A schematic of the circuitry of this system can be seen in Figure 8.

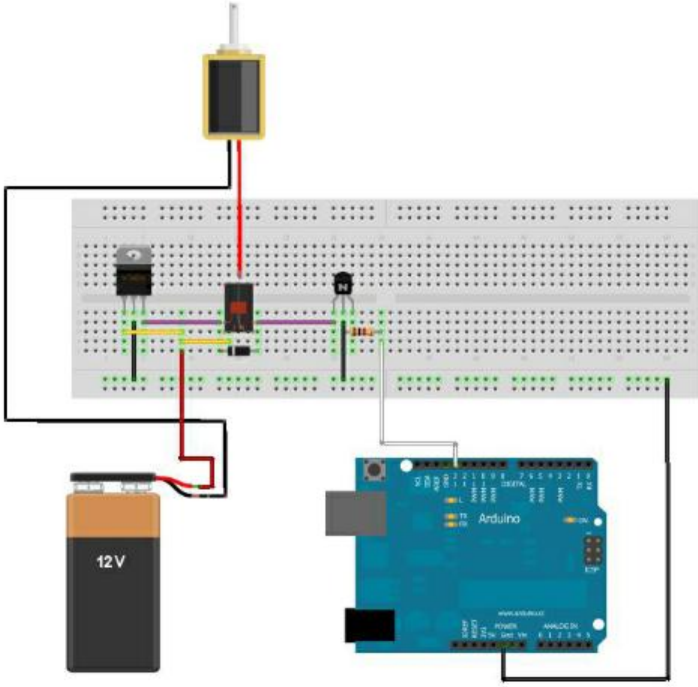

Figure 8: Circuit Diagram of Relay from Microcontroller to Valve

The twenty cell solar panel required a charging circuit in order to efficiently charge the 12 V battery. This circuit diagram can be seen in Figure 9.

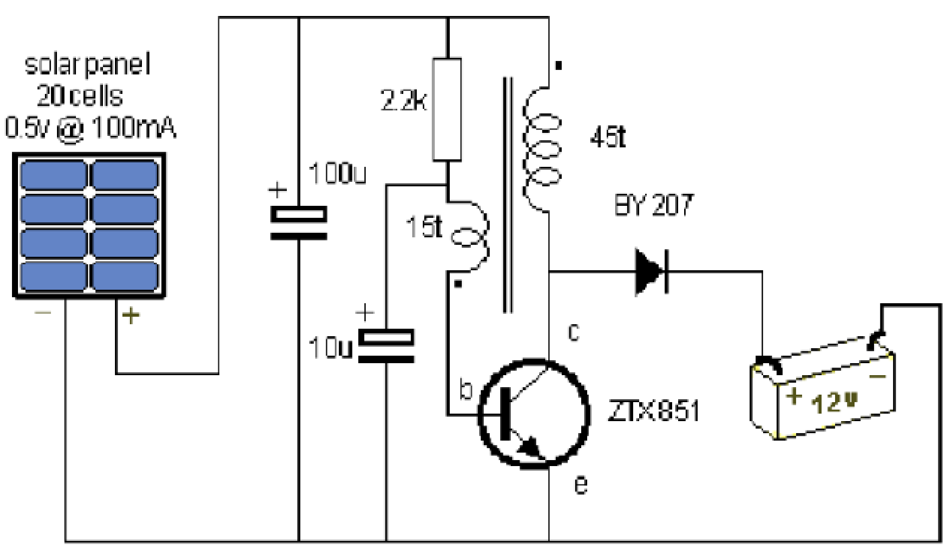

Figure 9: Circuit Diagram of Solar Charger

3.2 Materials Cost Analysis

The direct cost of each the subsystem was estimated and can be seen in Table V. With such a low estimated direct cost, the product can be sold at a competitive price based on previous market research.

Table V: Direct Cost Involved in Fabrication

Subsystem	**Cost**
Solenoid Valve	$100
12 V Battery	$15
Solar Panel	$30
Microcontroller	$20
Flow Sensor	$15
PCB	$25
Bluetooth Module	$45
Other components	$25
Total Direct Cost	**$275**

3.3 Eco Audit

An eco audit was performed using Cambridge Education Selector[6] in order to estimate the overall footprint of the device. Assumptions were made as to the distance that each component would be required to travel from its manufacturer. The end life of each component was chosen to be a landfill, except the battery which was down cycled. The product life was set to be 10 years. Results of the Eco Audit can be seen in Figure 10. The total energy involved in producing the device and transporting it to the user is 2.8 GJ. The majority of the energy consumed and CO_2 pollution is due to the embodied energy of the materials. 80% of the poor materials performance is due to solar cell. It should be noted that the manufacturing energy and footprint is included in the material value for all components but the brass solenoid valve.

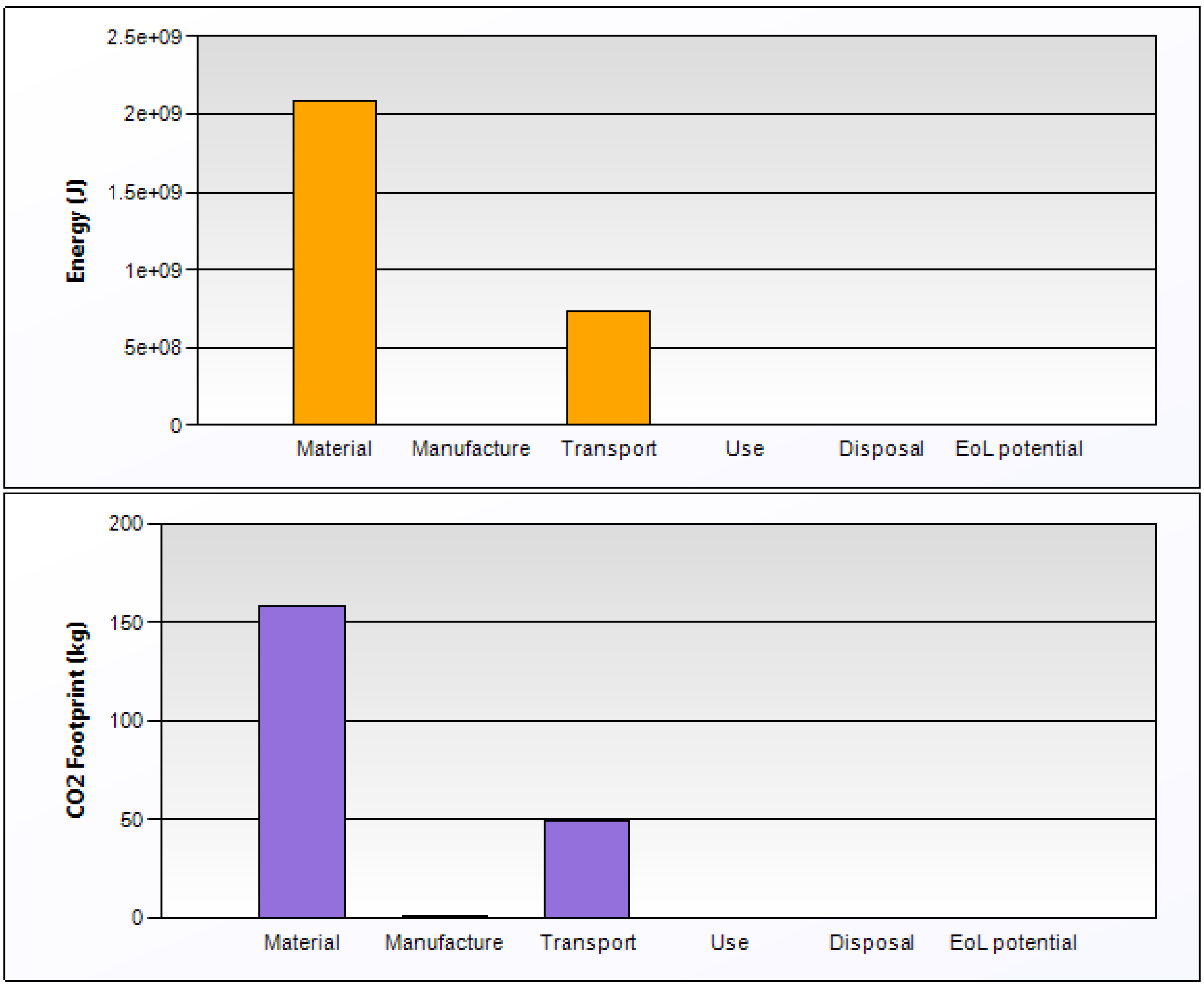

Figure 10: The results of the Eco Audit are shown in these two graphs of CO_2 footprint and energy consumed.

4. Design Verification

The following section will report on the nature of the experiments performed as well as the experimental procedures.

4.1 Construction of Test Jigs

Due to cost constraints, the pump used was the Grundfos nonsubmersible circulation pump (P/N 59896341) because it was readily available. The Grundfos pump has only an outlet water pressure of only about 3 psi, but can reach flow rates ranging from 0 - 17 gal/min. This is not an accurate pressure that the water circuit breaker system would see in application. For this reason, the pump was only used to test the device's electronics and software. To test the system at realistic pressures that would be seen in application, the valves were each connected to a hose. A pressure meter was also connected to record the pressure drop across each valve (Figure 11).

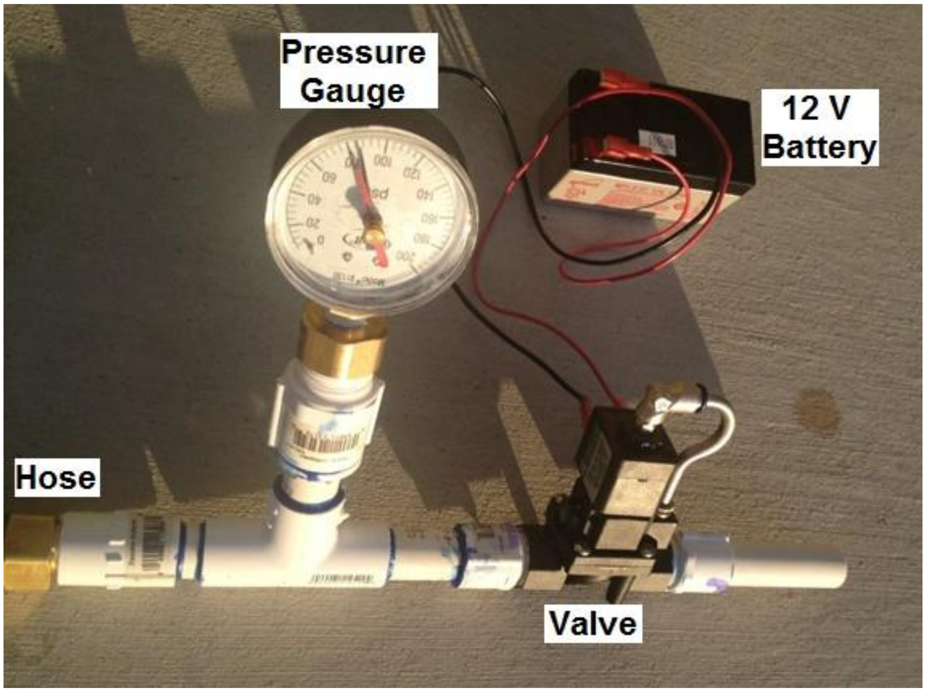

Figure 11: The image shows the test setup for the pressure tests.

The software test jig consisted primarily of PVC piping and pipe fittings with the water circuit breaker system in series with the pipe. The 10 gallon water reservoir was housed in a 30 gallon HDPE tub. The pump required an inlet pressure of 1.3 psi, or a reservoir with an elevation of 3 ft above the pump (Figure 11).

Figure 12: The image shows the test jig for the software tests.

4.2 Procedure of Pressure Test

Each valve was tested for 10 trials by applying and removing 12 V to activate and deactivate the valve. The pressure was recorded while opened and closed to calculate the pressure drop across the valve. The performance of each valve dictated the decision on which to use for the final design. Water quality at the outlet of the valve was also observed as well as any leaks in the system.

4.3 Procedure of Software Test

Following the pressure test which tested the system's mechanical ability to perform the task at hand, the software and electrical circuitry was to be tested using the recirculation pump. The software was altered for the tests in order to simulate actual environment in a shorter period of time. For example, a device installed in a residential plumbing system would require a sample period of approximately seven days, where as the sample period chosen for the test was 2 minutes and 40 seconds.

During this sample period, the software on the micro controller calculates an average flow rate every 5 seconds, called block rates. These block rates were then grouped in fours and averaged. The results were placed into an array to find the maximum of all averaged block rates. After the sample period, if the flow rate exceeded the maximum block rate for a period of 100 seconds, the software would apply a voltage to the relay and trigger the solenoid valve (Figure 13). Table VI shows the software differences between the test set up and realistic software specifications for a system installed in a residential plumbing unit.

Table VI: Variation of Tested Software and Application Software

	Tested Software	Actual Residential Software
Size of Block Rate	5 seconds	~1 minute
Sample Period	160 seconds	~7 days
Valve Trigger Time	100 seconds over max rate	~30 minutes over max rate

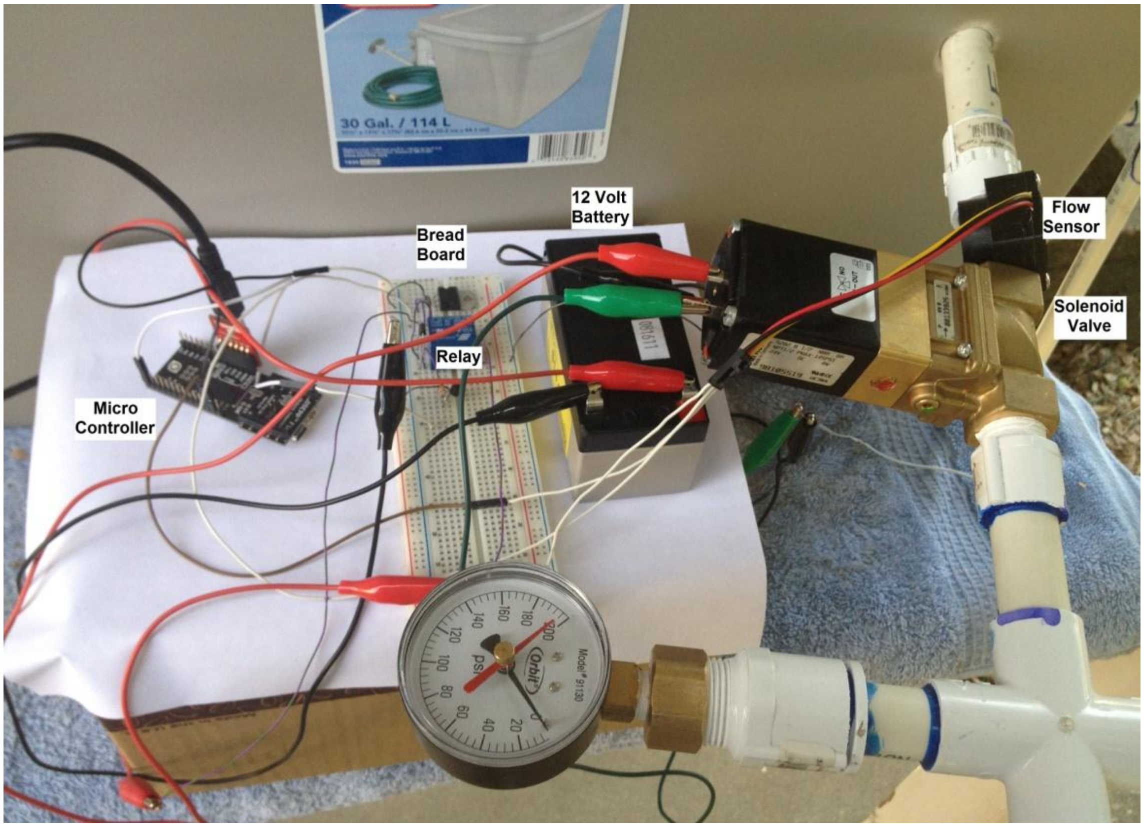

Figure 13: The image shows the entire system, including valve, sensor, microcontroller and circuitry.

For each trial, the sample period experience random changes in pump settings between off, low, medium and high (Figure 14). Once the sample period was over, the pump setting was switched to high, to simulate failure and flood. The time between when pump is switched to high and when the valve is closed was recorded compared against the programmed time of 100 seconds.

This experiment is performed to verify that the time to actuate the valve in practice is the same time that the software is programmed to allow.

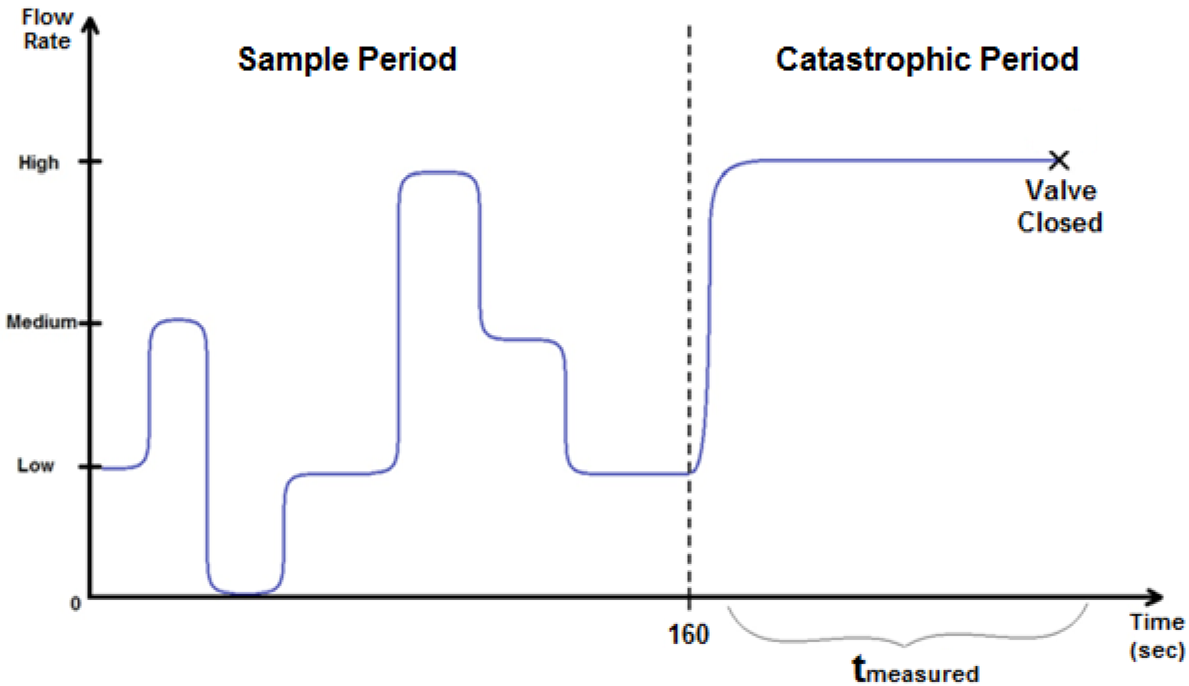

Figure 14: The schematic graph gives a visual of the overall experiment and the variable being measured.

5. Results

The following section will report on results from the pressure and software tests previously mentioned.

5.1 Results of High Pressure Test with Hose

The results of the valves attached to a residential water hose for 10 trials were averaged and compared for each valve. These averages can be seen in Table VII. There was a visual difference in water quality between the Bürkert (Figure 15) and Spartan (Figure 16). While Bürkert water flow was similar to that which would come out of the hose, the Spartan valve showed visual signs of low velocity flow.

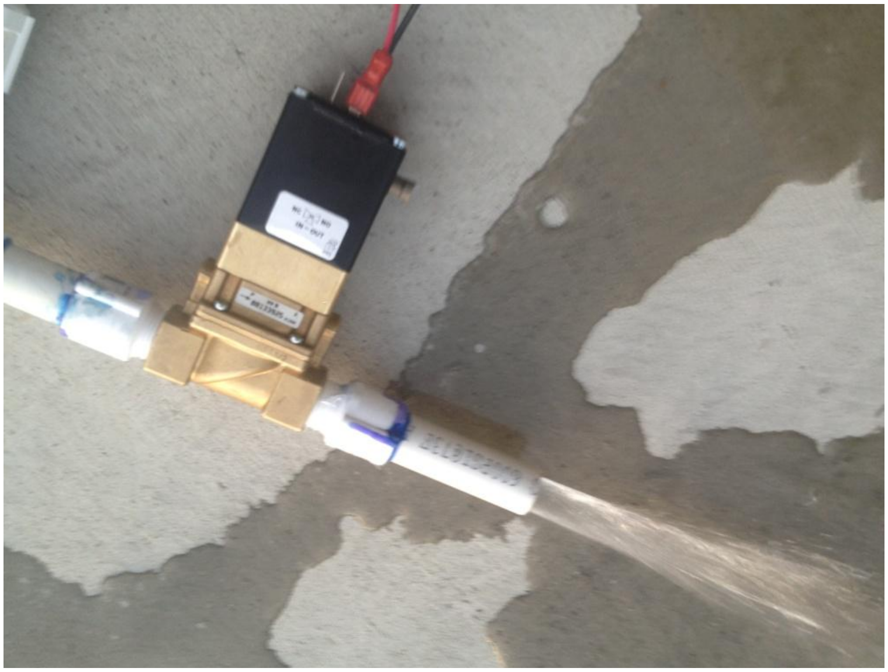

Figure 15: The image above shows the open Bürkert valve with high velocity flow at its exit.

Figure 16: The image shows the open Spartan valve with a trickle like flow at its exit.

Table VII: Comparison of the Performance of Valves

Valve Brand	**Avg. Stagnation Pressure**	**Avg. Static Pressure**	**Avg. Dynamic Pressure**	**Leak/No Leak**	**Water Quality**
Bürkert	2 psi	87 psi	85 psi	No Leak	No Visual difference
Spartan	83 psi	87 psi	4 psi	No Leak	Quality Compromised

Due to the Spartan valve unable follow the design requirement of no disruption of water quality, it was considered a failure at these high pressures. Therefore the Bürkert valve was chosen for the final design and was used in the following experiment.

5.2 Results of Software Test with Recirculation Pump

Results from the software test can be seen in Table VIII where the flow velocity for each trial varied between off (O), low (L), and high (H). All trials were either equal to or exceeded the theoretical time of 100 seconds.

Table VIII: Results of Software Test

	Sample Period (seconds)										
Trial	20	40	60	80	100	120	140	160	**Time Measured (seconds)**	**Theoretical (seconds)**	**Offset (seconds)**
1	O	L	L	L	L	L	L	O	105	100	5
2	O	L	M	M	L	L	O	O	110	100	10
3	O	L	L	H	M	L	L	O	108	100	8
4	O	L	L	O	O	M	M	O	107	100	7
5	L	L	M	O	H	H	M	L	105	100	5
6	H	M	M	M	M	H	M	L	107	100	7
7	M	M	M	O	O	O	H	O	105	100	5
8	M	M	L	L	H	H	L	L	108	100	8
9	L	H	L	H	L	H	L	L	100	100	0
10	M	M	O	L	L	H	L	L	115	100	15
									Standard Dev 3.887		**Average 7**

A graph of trial 10 can be seen in Figure 17 as an example. Note that the blue region is the sampling period with random simulated water usage. It should be stated that the units on the y-axis were intended to be L/min, but are off by at least a factor of two. Therefore the axis is labeled as counts from the sensor.

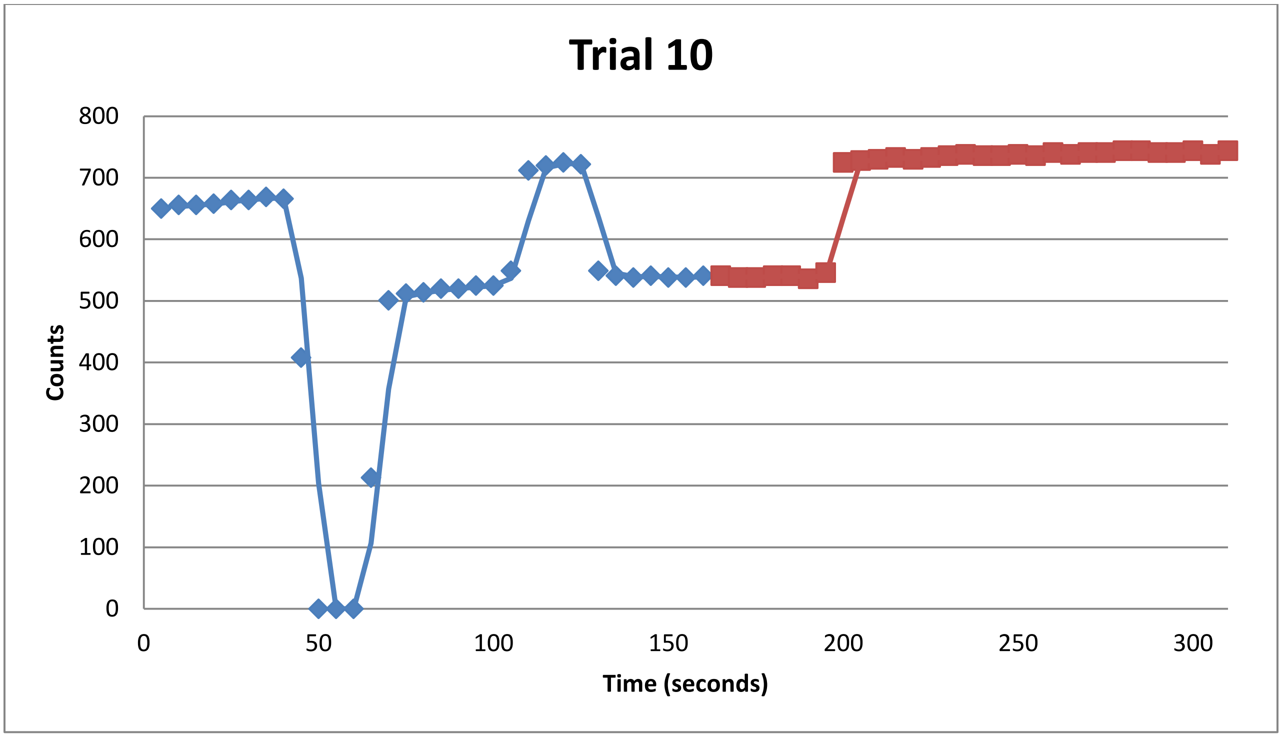

Figure 17: The graph above shows the tenth trial in the experiment. The blue region of the graph is the sampling period.

6. Discussion

Although two valves were supplied for the project, the Bürkert valve far out performed that of the Spartan valve based on outlet flow rates during the pressure test. The Spartan valve experienced a significant pressure drop across it while the Bürkert's drop in pressure was negligible.

Results of the software test were indicative of good response time in the event of a catastrophic simulation. Although almost every trial was late to actuate the valve, this result is better than responding too early, which would raise the possibility of a false alarm.

The test set up and methodology (Figure 18) was a accurate way to test the software of the water circuit breaker, though the software is not yet perfected. The current software does not integrate the incoming data, but rather calculates an average of maximum flow rates. This average maximum must then be exceeded for a period of time in order to trigger the solenoid valve. This is not the optimal logic for this application, because in the event that the leak in a residence is the only source of water consumption, it is entirely possible that the flow rate will be well below the average and will go unnoticed. Instead integration would work to better detect a leak based on parameters determined in the sample period. The software of the program is the critical piece in the design that will make or break further development of this design.

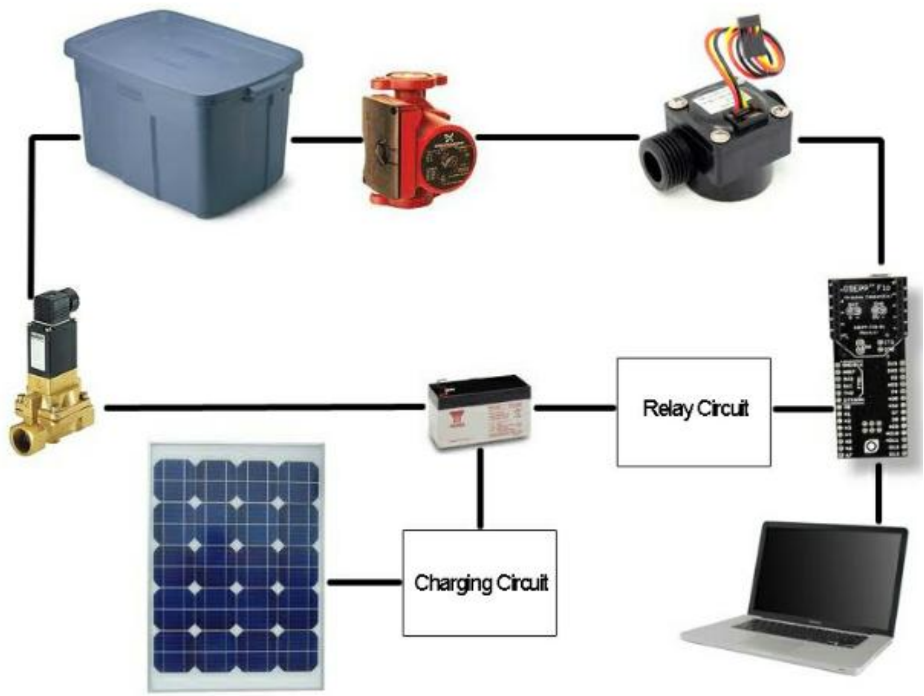

Figure 18: The image shows a schematic of the test system and the communication between components

Despite the system's flaws, it would still be of use when installed in a residence. Better practices and preventative systems such as this are desperately needed in order to give the Earth the opportunity to renew itself in response to the abuses of humankind.

7. Conclusions and Recommendations

The following are conclusions as well as recommendations for further development and improvement of this system.

1. Experimentally measured time to actuate solenoid valve is longer than the theoretical time programmed on the microcontroller by an average of 7 seconds and a standard deviation of 4 seconds.
2. Recommend fabrication of PCB and housing for circuitry in order to protect and maintain high-quality electrical connections.
3. Recommend monitoring actual household flow rate for a period of a week to better determine the exact software parameters needed to detect abnormality.
4. Recommend software calculates an integrated flow velocity with respect to time and use as the threshold for determining normal flow. The length of this integral can be automatically changed and is dependent on data obtained in the sample period.

8. References

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